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Giving depth to the surface: An exercise in the Gaia-graphy of critical zones

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Abstract

Foregrounding the importance of soil and more generally the surface of the Earth – what is now often called the critical zone (CZ) – remains very difficult as long as the usual planetary view, familiar since the scientific revolution, is maintained. In this joint effort coauthored by a landscape architect, a historian of science and a geochemist, we propose what is called in history of drawing an *anamorphosis*, that is, a distortion of image made through an instrument or a change in perspective. Such anamorphosis allows us to shift from a planetary vision of *sites* located in the geographic grid, to a representation of *events* located in what we call a Gaia-graphic view. We claim that such a view is much better suited to situate the new actors of the Anthropocene because it brings pride of place to the CZ.

Keywords

Anthropocene, cartography, critical zone, geochemistry, projection

> One would be required merely to replace the present cosmogonic hypotheses by new ones, and to apply new scientific and mathematical scrutiny to certain philosophical and religious viewpoints called into question by advances in scientific thought. This has happened before in the creation of modern cosmogony. The biosphere. (Vernadsky, [1926] 1998: 55)

Introduction

This paper presents the first results of a search for an alternative representation of the thin surface of the globe. It is based on a long-term study of the network of Critical Zone Observatories (CZO) and stems from a dissatisfaction felt by CZO practitioners in representing their own objects of

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investigation. The novel manner of representation offered in this paper is the result of an unusual collaboration between an architect specialized in landscape planning (AA), a sociologist of science engaged in a study of the field (BL) and a geochemist who heads the French CZO network (JG).

In the singular, 'the Critical Zone' (CZ) designates the (mostly continental) layers from the top of the canopy to the mother rocks, thus foregrounding the thin, porous and permeable layer where life has modified the cycles of matter by activating or catalyzing physical and chemical reactions. Those complex biogeochemical reactions generates a kind of skin, a varnish, a biofilm whose reactivity and fragility have became the central topics of multidisciplinary research around the disputed concept of the Anthropocene. The CZ is not unrelated to the concept of Gaia in the meaning given to it by Lovelock and Margulis' Gaia hypothesis (Dutreuil, 2016).

In the plural, 'critical zones observatories' (CZOs) is more and more often used as a term that points to the collaborative work between hydrologists, soil scientists, geochemists, geomorphologists and geophysicists, and ecologists, on well-instrumented field sites, ranging from a few hectares to large watersheds (Brantley et al., 2017; Richter et al., 2015, Gaillardet et al., 2018). Like the Long Term Ecological Research sites (LTER) (Haase et al., 2018), the aim of those networks is to share instruments, data, and models among what could be called 'field laboratories' to provide a close description of the complex dynamics of those highly heterogeneous regions of the Earth at the time when human forcing is radically transforming them. Each field laboratory gathers disciplines around a key question – pollution, flood, acid rain, nitrate fertilization, etc. – and relates those fine-grain data to fundamental science in order to obtain a representative sample of the various processes that cannot be easily detected or represented with overall models of Earth System Science (ESS) (Brantley et al., 2007).

One of the problems researchers face in picturing the CZ is to give it a shape. Compared with the immensity of the geophysical globe, the intricacies of the CZ vanish from view. This is the limit of what could be called the 'planetary view' of the Earth made familiar since the time of the scientific revolution and reinforced by the iconic image of the Blue Planet (Grevsmühl, 2014). In such a planetary view, where Earth is viewed as if from out in space, all life forms as well as humans are squashed to the point of becoming invisible. This creates a cognitive dissonance since there is no commensurability between the lived experience of being situated in the CZ and the image provided by the planetary view. Even though the CZ is where all human and non-human forms of life are active, there is literally *no room* for following their distribution and entanglement from the lower atmosphere to deep rocks.

The second difficulty is that the planetary view localizes any point on the surface of the Earth according to the cartographic coordinates of longitude and latitude. Although extremely useful for drawing a static base map of *places*, it does not provide the opportunity to develop a good feel for the crucial importance of geochemical *cycles* that have to be represented dynamically. Thus, the two most important features of the CZ – the central importance of the Earth's thin pellicle and of its dynamic cycles – are not easily represented for practitioners and even less for the stakeholders scientists try to address.

Our goal is to bridge the gap between the experience researchers have of their CZO and the images they give of themselves to the public and to the other disciplinary fields with which they collaborate. The CZO, just like the LTER, are reconstructing a view of the Earth that is much more concrete, dynamic, complex, heterogeneous and reactive than what can be captured through the cartographic imaginary of points defined on a map by longitude and latitude. Even though every CZO is local and answers local questions, each of them contributes to successive segments of the geochemical cycles that should be inserted into a global framework at some point. Because the planetary view does not provide a good grasp of the multiplicity of nested envelopes necessary for sustaining life, another frame is called for. Instead of being viewed from outside, as in the planetary view, such a frame should provide a view *from the inside*, providing a much better feel for what is necessary for every life form to subsist (Sloterdijk, 2009).

This is even more necessary at the time of the Anthropocene – whatever its eventual stratigraphic definition (Waters et al., 2016). In addition, there is also a necessity to cultivate the habit of considering the scientific activity itself as firmly 'situated' inside the CZ that it detects not from out in space but in the midst of controversies (Latour, 2004). Scientists of the CZ cannot expect to escape from political questions linked to their terrestrial entanglement (Haraway, 2016).

To sum up, even though planet Earth is original precisely because of the CZ, it is still represented mainly according to principles not different from those used to characterize a dead planet such as Mars or Venus. To represent the Earth in a novel form – as a kind of *new* new world to be discovered yet again (Latour, 2017a) – we wish to provide a new projection principle allowing the foregrounding of the two features that are sorely missing in the planetary view, namely the thickness to be attributed to the CZ and its geochemical cycles. This first step is an exercise in what could be called 'Gaia-graphy' and relies on image as well as imagination. Just as was the case at the time of the Copernican revolution (Koyré, 1957), it is an exercise in *cosmography*, that is, on how artistic imagination may come to the aid of new scientific concepts (Ait-Touati, 2012). What follows offers a speculative scheme, not yet a model. The obvious next step would be to use the grammar proposed in this speculative paper to gather, organize and represent data coming from actual CZO.

Each of the following sections is concerned with one of the problems presented above: (1) What kind of projection may give depth and volume to the thin superficial CZ? (2) How to foreground geochemical cycles in a credible way? (3) How to localize a dynamic phenomenon in this new system of coordinates?

(1) What kind of projection may give depth and volume to the thin superficial CZ?

Existing visual displays of the CZ correspond mostly to what is called in architecture a 'block diagram', that is, a vertical representation of a cross-section of the Earth's surface, much like a building or a garden, often in axonometric view, offering no more than a slice isolated from the rest (Figure 1). The classical 3D representations of soil scientists belong to this category. In such a block diagram, whatever the scale that is chosen, various elements are layered on top of one another from bottom to top, rock layers occupying the deepest level and humans occupying the highest and admittedly most recent layer (Zalasiewicz et al., 2016) – various life forms occupying the middle, atmosphere being on top. This is unfortunate since both the lower and upper limits of the critical zone in these block diagrams are ill-defined.

The problem with such a representation is that it breaks down the connections between the various phenomena CZ science are trying to assemble. By ordering objects in layers and relying on a 'zoom' to go from one scale to the next, such a picture is unable to represent the internal feedbacks and the dynamic interfaces of CZ processes. Those processes vary enormously in scale – from the highly local to the planetary – and in time – from microseconds to billions of years. In addition, most processes cannot be easily layered on top of one another given the number of feedbacks between the various agents working through the CZ. By definition, every part of a CZ redistributes what is local and what is global in a different way from each other part – a watershed is neither local nor global in the same way as a population of earthworms, CO_2 in the atmosphere, forests or industrial corporations would be, even though all of them would show some trace of their process trajectories in one of the block diagrams chosen as a starting point. Thus, one of the key

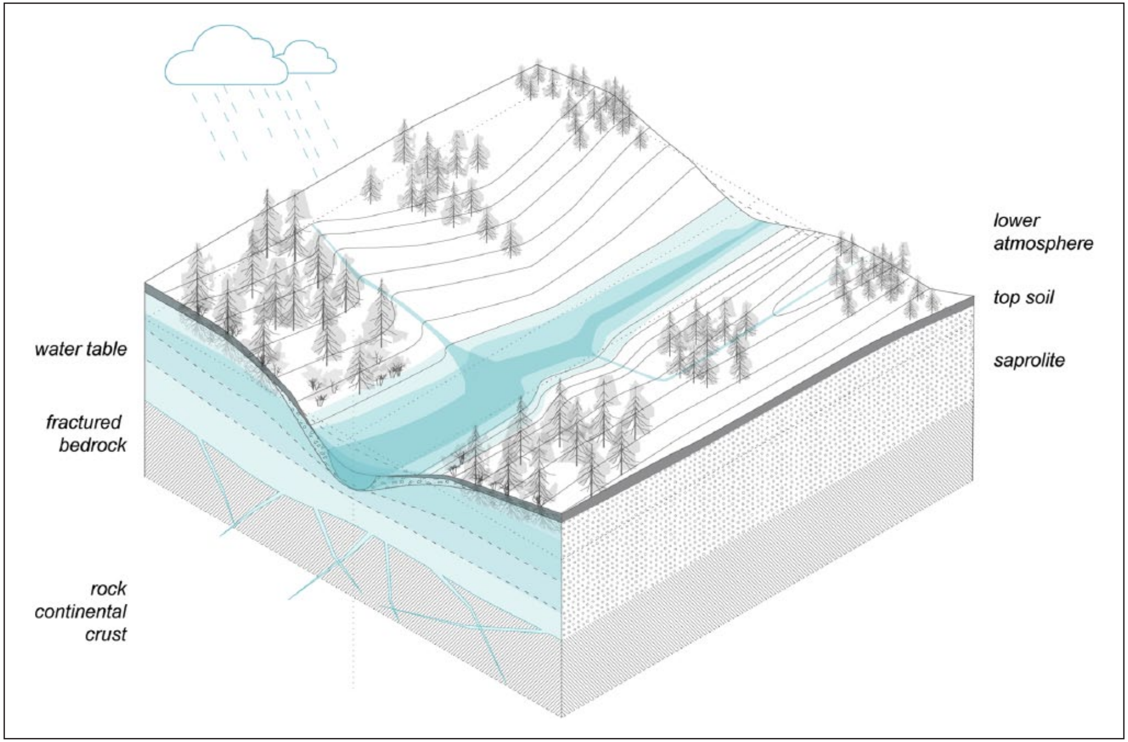

Figure 1. A typical example of a block diagram classically used in the Critical Zone Observatories to describe the thin pellicle of the Earth that they are studying.

specifications of our projection should be to provide an alternative vision of this complex distribution of local and global phenomena (Latour, 2017b).

This is why we have attempted to build a visual display that allows the smooth passage from one scale to the next without being torn between a view either too global (the whole planet) or too local (an isolated 3D cross-section). To do so, we decided on two simultaneous operations: we keep the order of layers from bottom to top but we abandon the block diagram by *flattening* all the different components around a *central axis* chosen as a reference point. Operations are summarized in Figure 2 and Figure 3.

At first (Figure 2), we keep the layers in the way they are ordered in the classical view of geography textbooks: the lower atmosphere; soils (from the thin litter all the way down to the saprolite, the part of the dismantled bedrock that has lost its soluble elements and has become porous); the terrestrial crust formed of hard parent rocks; the Earth's mantle and, finally, the Earth's core. But then, we deploy those successive strata around *any point chosen as a reference* (it can be any specific CZO one chooses to start from). Layers are now arranged in tiers around the same circular plane. To begin with, we keep the same order and start to build the environment, through a very simple geometric construction, as a series of nested circles, each constituting one of the envelopes of the terrestrial habitat chosen as reference (Figure 3).

However, keeping the usual order would again make the top soil as well as the CZ disappear if we wanted to represent all successive layers on a geologically valid scale. This is the usual problem with all maps and the reason why CZ scientists are rightly called 'superficial' by their other colleagues from deep Earth sciences! They deal indeed with critical but vanishingly small phenomena when planet Earth is viewed from out in space as a planet among others.

This is why, in a second move, we propose to solve the problem of the disappearing soil surface by *reversing* the order of strata and placing the Earth's core as well as the mantle at the *periphery* of the projection. We now have all the room available to scale up any of the various layers making up the CZ, thus following what is called in projective geometry an anamorphosis, a projection that maintains relations intact but modifies the relative scale so as to outline specific phenomena (Baltrusaitis, 1984). Thanks to this anamorphosis, the layers that are really critical for life on Earth are now fully visible instead of being squashed as in the other representation. The superficial now becomes central.

Just as we did in Figure 2, we flatten the different layers around the central point as so many nested circles without losing the order of the various strata (Figure 3). However, the general feel is entirely different. First because we now place the atmosphere *in the center*, represented as a circle inside which life forms mostly reside – and not as an infinite horizon above the rest of the Earth. Second, the relations between depth and surface, although maintained, are now reversed: the Earth's core is pushed to the periphery and it is now the components of the CZ that can be displayed in greatest detail. The main advantage of such anamorphosis is that the extreme complexity of the CZ may now be rendered visible by increasing or decreasing the relative thickness of the different components (Figure 3). Depending whether one wished to insist on top soil, water circulation, perched water table, agriculture or tree roots, one may simply vary the relative proportion of the layers without altering the order in which they have been classically arranged. Each CZO is focusing on specific questions that now can be more easily represented. Everything is now visible as if we were looking at the Earth simultaneously *sideways, from the bottom* and *from the inside*, a point of view utterly different from the planetary view we criticized above.

Even though it might look odd at first, our claim is that such an anamorphic projection provides a representation of the way we inhabit the Earth that is much more commonsensical than the view from out in space. No matter how essential for geophysics, the Earth's core and mantle are very foreign to living organisms, who are essentially surface-bound creatures. This is why it feels right

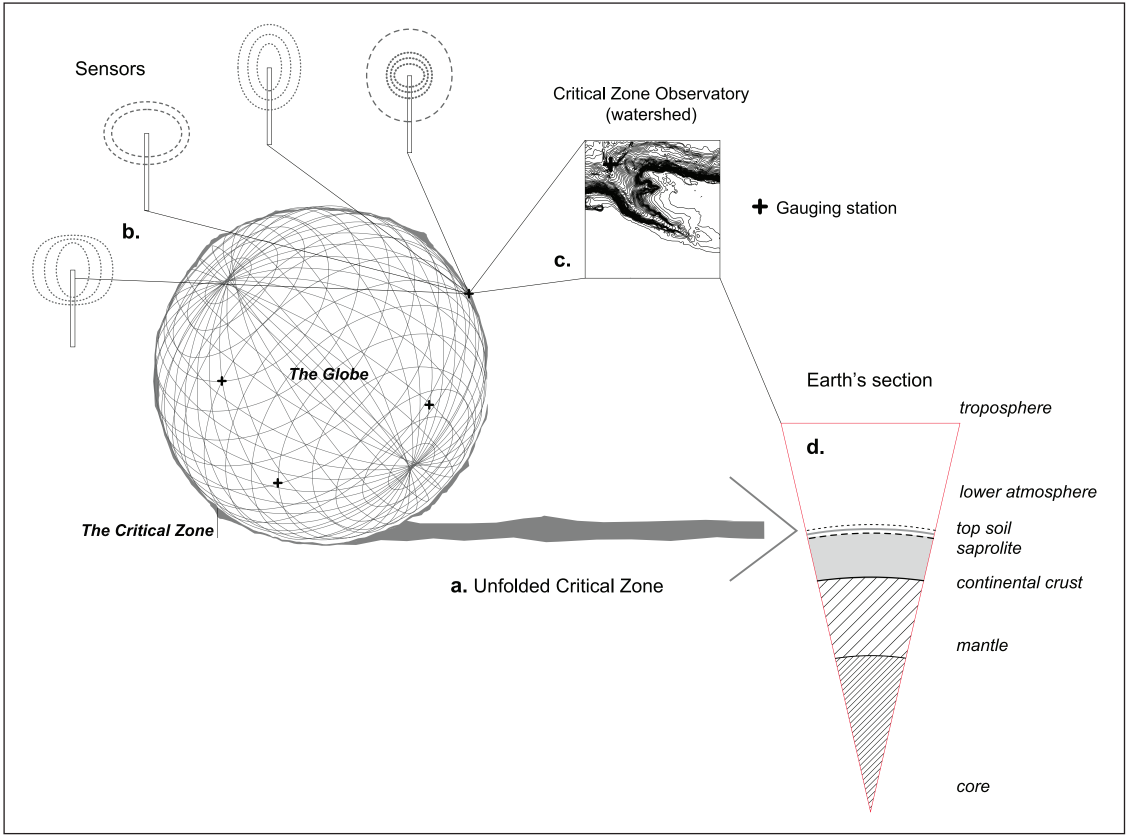

Figure 2. From a global to a 'Critical Zone' perspective. The critical zone (CZ, Figure 2a) is a thin pellicle at the Earth's surface where life and human activities are concentrated. To deal with its large heterogeneity on the globe, scientists have designed local 'critical zone observatories' (CZO, Figure 2c), such as watersheds, equipped with sophisticated sensors (Figure 2a) monitoring the local CZ continuously and for long time periods, gathering data for different parameters used by scientists in conceptual models. Figure 2d shows, of course not at the right scale, from the top of the troposphere to the Earth's center, the position of the CZ in a classical geophysical description of the Earth.

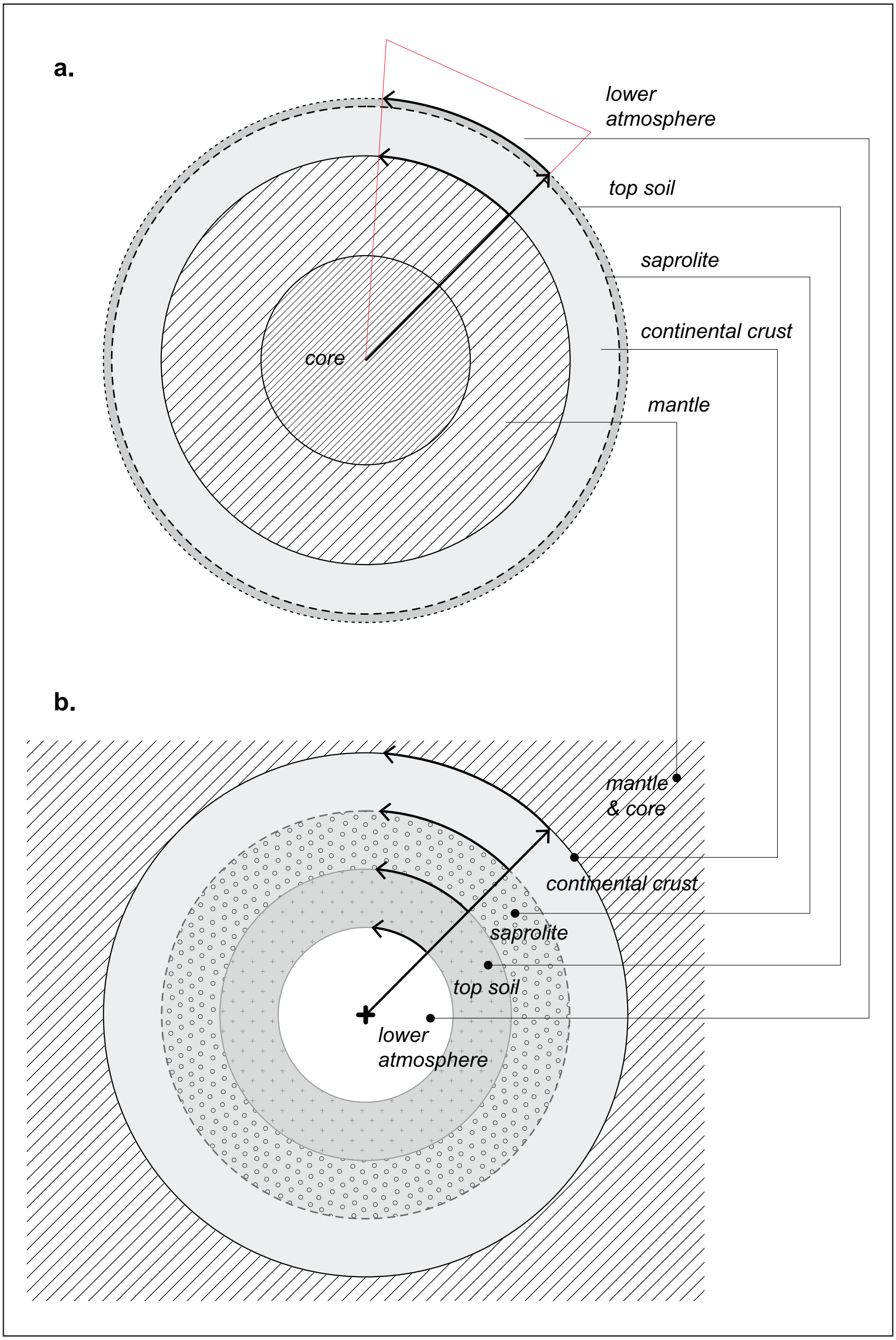

Figure 3. A new conceptual representation of the Critical Zone Observatories. The different components of the CZ are deployed in nested circles around a reference point (that can be any specific CZO) in a circular plane (Figure 3b). This operation is an anamorphosis that places the layers that are really critical for life on Earth in the center instead of being squashed as in the classical representation (Figure 3a). The arrows indicate the way the different layers are geometrically constructed.

to have them thrown outside of the center and considered in effect as peripheral to our attention. Conversely, it is straightforward to give pride of place to the highly complex and thoroughly heterogeneous CZ, since it is what is most important for life forms and, at the time of the Anthropocene, what is most fragile and most threatened. Finally, it makes good sense to represent the lower atmosphere as the center of the display since it does not float in unbounded space but is strongly coupled with the soil surface, giving a strong indication of the tiny respiratory mechanism from which all life forms breathe. If we pollute the atmosphere or mess it up, there is no other horizon to which we could escape, contrary to the impression given by the traditional planetary view.

The crucial point is that superficial layers now acquire the greatest pertinence. Since we keep the older circular shape of traditional cartography, the viewer is given a strong feeling of being *inside* and bound by revolving cycles (see the next section). In a very powerful way, provided we situate ourselves in the map, at the border of the vortex simulating the atmosphere, with the soil, the fractures, the trees and the roots all around us and weighing on us, we may begin to feel that the skin of the Earth has been, so to speak, *reversed like a glove* and that we are now *inside* a deep set of envelopes instead of *on* the surface of a planet. If it is true that the imagination of infinite space dominated by humans has been largely influenced by maps of the globe from the 16th century onward (Farinelli, 2009), it is interesting to speculate what alternative projections might do to the self-image of the 'anthropos' of the Anthropocene (Hamilton, 2017).

(2) How to foreground geochemical cycles in relation with solar activity

The main advantage of using the old principle of concentric circles to situate the point of reference is that circles are also a great way of representing *cycles*. This is what we wish to do in this second section. Circles should not be read topographically but *cinematically*.

By modifying the thickness of the circles, their direction and eventually their color, we could begin to register the different processes that shape the CZ, such as erosion or the transformation of rocks to soil, as well as slower geophysical phenomena represented by cycles further toward the periphery of the diagram. Instead of considering planet Earth as if from out in space, we grasp it as a helix, a vortex, or, as a series of nested merry-go-rounds swirling at different velocities with the chemical elements or molecules being considered as cascading from one circle to the next in both directions. It is noticeable that this alternative representation corresponds fairly well to what Vernadsky pointed out in his definition of the biosphere (Vernadsky, [1926] 1998). Although without historical evolution, his view of Earth's CZ was essentially dynamic based on the movement of chemical elements caused by the input of solar energy to the Earth's surface.

However, before we are able to give shape to such an energetic view of the Earth surface, we need to localize the main agents of those geochemical transformations. Those closely coupled agents are simultaneously deep Earth rocks, living organisms and the sun. This is where a Gaia-graphy grasps a different phenomenon from geo-graphy properly speaking. Matter modified by living organisms plays the central role, and in between the sun and deep Earth are given the same level of importance.

In Figure 4 we propose an axonometric view of the former Figure 3 to render visible not the position of the sun in a cartographic view, but its role in a dynamic geochemical view. The sun is now placed at the top of an axis – to pursue the merry-go-round metaphor – around which turns the whole set of nested cycles situated nearer the center of the reference point. The solar activity is represented as the projection of a cone crossing the flat surface where the concentric cycles are located. The activity of the sun extends its influence until it meets the other source of energy coming from deep Earth and its powerful convective movements which in Figure 3 have been moved

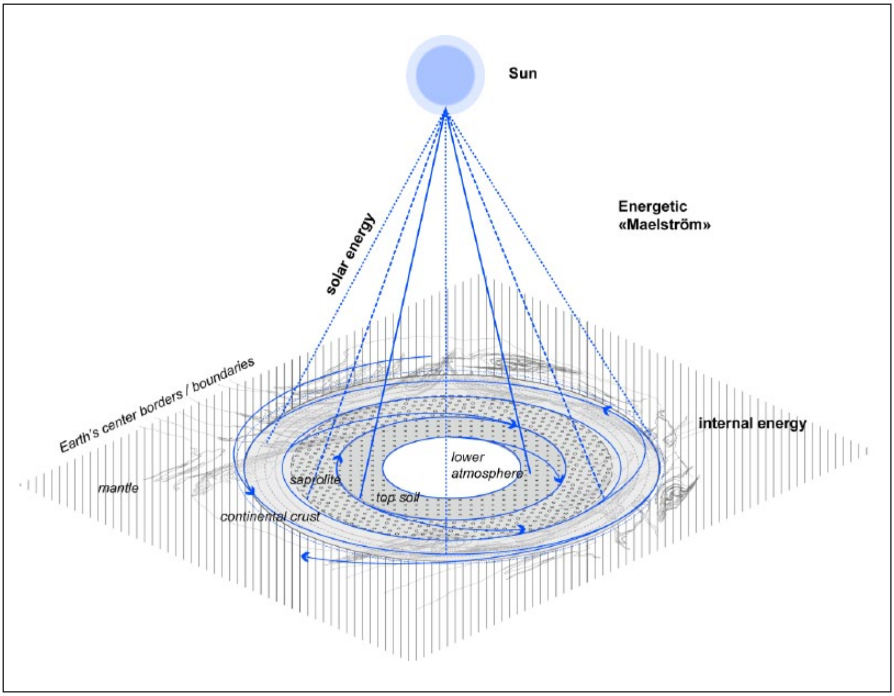

Figure 4. Axonometric view of the former Figure 3 made in order to render visible not only the position of the sun in a cartographic view, but also its role in a dynamic hydrological and geochemical perspective. This view shows that matter and elements are activated by a cosmo-tectonic circulation denoted here as the 'energetic maelstrom'.

to the periphery. (The energy provided by the sun is on average 340 watts per meter square compared with 0.07 watts per square meter coming from deep Earth; Berner and Berner, 2012.)

What is especially important to notice in Figure 4 is that this activity of the sun is essentially dependent on the ability of life forms to develop processes to harness a part of its energy. Without photosynthesis the sun would have no more influence on planet Earth than on Mars or Venus (Morton, 2007). This is what is meant by a *coupling* between the sun and living organisms: each transforms the other into an active agent. Thus, the shifting limits of the cone represent how much life forms have been able to make use of the sun's energy.

However, life seems to have an ability to infiltrate much further through many 'fractures' than what was thought possible years ago. This is why the shifting limit also allows us to picture the energy that has been harnessed by other life forms that do not depend directly on the sun to subsist (Trias et al., 2017). Thus, the two main sources of energy are indeed represented but without being conflated as in the usual planetary view: both 'geophysical' energy coming from deep Earth and the much more distant, and for most of the CZ the most relevant energy, coming from the sun. Both sources of energy, once again, that would not have that strong an impact if not for the invention of life. We all live in this maelstrom, spiraling in between those three sets of forces: deep Earth, sun and living forms.

It is interesting that such a representation of the sun's role on earth does not fit into the traditional cartographic problem of having to choose between Copernican and pre-Copernican world-views. It is indeed *heliocentric* since it makes the Earth turn around itself, but in a different energetic and non-astronomical sense of the words; and it is indeed geocentric since everything of relevance happens here ‘on Earth’, but earth defined *not* as a planetary body but as a fragile, thin and active CZ. In effect our model is exactly as geocentric as it is heliocentric, life being situated straight in the middle. In keeping with the Lovelock-Margulis’ hypothesis (Lovelock, 1979; Margulis, 1998), our model is *Gaia-centric*.

Life forms are in the middle of two sets of energy-giving mechanisms: the sun on top and deep Earth at the extremity. Whereas in the *geo*graphic representation, Earth is taken as a planet among all the planets as if viewed from nowhere, in this sketch of *Gaia*-graphy a crucial difference is introduced between the zones in which phenomena are influenced by the action of life and the zones where phenomena are not influenced by such action. This is an essential condition to test the Gaia hypothesis and to get away from the meaningless choice between ‘Earth is alive’ and ‘Earth is not alive’ (Dutreuil, 2018). On the CZ that we wish to foreground, it’s clear that the difference between biotic and abiotic processes has become moot. Because of the agency of life forms, atoms have spent time as constituents of organisms and at other times have been associated with other elements of the CZ.

What we try to foreground is the possibility of representing any CZO as the place of choice for testing the conflation of tectonic and solar forces as they contribute to what could be called the ‘cosmotectonic’ circulation of matter. For instance, the weathering of granite making up a soil mainly through the activity of life forms and water, the neutralization of CO_2 released by photosynthesized organic matter under decomposition, and the generating sediments that are transported in turn by the action of water – all those phenomena controlled by gravity and the action of the sun – before they are subducted in in the mantle, transformed into schists or eclogites before being sucked inside the mantle or reappearing in granite anew – waiting to emerge millions of year later at the mercy of new life forms once again (Zalasiewicz, 2010).

If our projection principle has some relevance, it is because it does not focus on any organism in particular, but on the transformations of matter and of chemical elements circulating from one circle to the next in both directions, either through organisms to other organisms, or through rocks to the atmosphere, or from atmosphere to organisms.

What is taken as central is thus not the *stability* implied by the cartographic vision of *Galilean objects*, but *migratory states* each with its own movements, weaving atoms and organisms together. Each element circulates, its position being constantly modified by the chemical and biological constraints. This is why *residence time* becomes central to any description of this vortex. Residence time defines the period during which an element does not change its molecular form and remains in the same circle – a reservoir in the geochemical sense – before migrating to another one, quicker or slower, depending on the kinetics of the reaction to be followed. Residence time has become a central piece of information to characterize the myriad of phenomena in which we find ourselves embedded. For instance, it is because the residence time of CO_2 in the atmosphere is very low compared with the residence of carbon in rocks that the CO_2 is accumulating dangerously in the atmosphere. We claim that our solution breaks down the main limit of the planetary view that conflated the *circular* notion of the Blue Planet with the *cyclical* nature of CZ phenomena.

However, we can now reuse the circular theme, so important in the history of cartography, to focus directly on geochemical cycles. Whereas life on the Blue Planet was barely visible, it is now central because we draw its energetic dimension à la Vernadsky on top and in place of the geographic world view. The new problem is of course to determine on which condition one can locate a point of reference by use of this new Gaia-graphic principle. The next section pursues such a lead.

(3) How a new system of coordinates could help capturing the signature of CZ processes?

We are now in possession of a principle of representation that pays full justice to the relevance of the CZ and that, through an anamorphosis, accentuates both its centrality for us humans and its role as the interface between the two sources of energy that life has been able to make use of.

It is because of its role as an interface that it is difficult to define and to delineate exactly the limits of the CZ, even though upper and lower limits are roughly visible. Hence the canonic definition of the CZ extending from the lower atmosphere to the mother rocks (Brantley et al., 2007). Thus, the limit of the CZ should remain flexible and will vary according to the time dimension and the scale chosen for a specific study.

What is clear is that the CZ has progressively been engineered by life forms which learned over the eons how to use the sun and deep Earth energy to transform matter, thus unexpectedly creating the conditions necessary for other life forms to subsist. Reactions between CO_2 and rocks, for instance, elaborate a soil where water dissolves the minerals and provides the nutrients necessary to the entire ecosystem. The functional importance of such transformations explains why CZ scientists and geochemists multiply the instruments that allow them to capture and quantify the migration of chemical elements and why they use increasingly sophisticated tracers (such as isotopes) to follow how elements move from one circle to another (Chen et al., 2014). A cycle is thus not defined as what happens to one element but rather *how* one element or molecule – water, sulfur, CO_2 etc. – shifts from one circle to the next. It is this conception of element cycles jointly modified by deep Earth energy (mostly coming from Earth cooling), sun radiation energy and the action of organisms, that gives its specific flavor to any Gaia-graphic description of the CZ. Everything moves and is transformed whatever element you choose to consider, offering a dynamic vision that it would be very difficult to express through a cartographic view of objects standing side by side in space (Lenton and Watson, 2011; Lenton et al., 2016).

And yet, as is well known by any user of maps or GPS, the decisive advantage of the conventional cartographic projection is that it allows a quick *localization* of any site through two and only two measures, longitude and latitude – to which height can be added. It is clear that we have no hope of emulating such a convenient and ubiquitous system for ordering the planet with Cartesian grids (Higgins, 2009). What we claim, however, is that the projection we propose better approximates the dynamic nature of hydrological, matter and geochemical cycles than the Cartesian system of coordinates. For this, we propose to follow a given site or a given process not by its longitude and latitude, but by the way it *bifurcates* from one circular cycle to the next. In other words, we are not looking for the position of a *place* but for the *signature of an event*. Such a signature is defined as the way it creates a *spiral* (Figure 5).

Any spiraling event may start at any point in one of the cycles. From low atmosphere – our new center – towards deep rocks in the inner recess of the planet; or from this inner recess to the center – that is the 'superficial' layer of the CZ in the older projection. We may also add a direction and a color to those two movements, the centrifugal – what flees from the center to the deep rock, and the centripetal – what moves from the (new) periphery to the center.

The interesting feature of this definition of an event by its signature in the form of a spiral, is that it is now possible to visualize the difference between what happens in the center of the model activated by life forms because of the sun's energy – periodic and chaotic processes with a very short residence time and high chemical turnover – and what happens at the periphery – much slower chemical and physical reactions on much longer timescales activated by mantle convection. The double process of sedimentation and uplift are thus rendered visible and so is their difference of rhythm. The Earth appears clearly as doubly closed, at the center by quick cycles and at the periphery by slow tectonic moves. In the middle are all the movements of intermediary speed and scale.

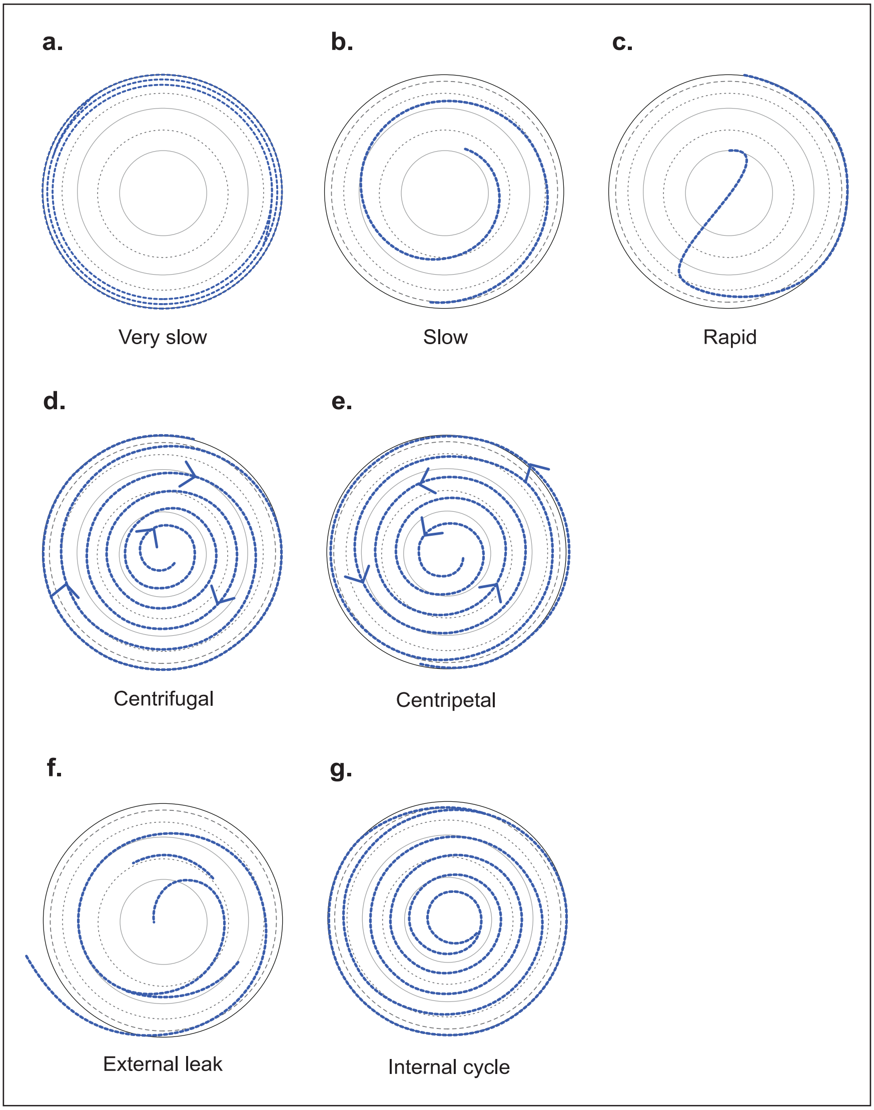

Figure 5. Visual repertoire of mass and geochemical movements (processes) in the CZ in the new system of coordinates proposed in this paper. (a), (b) and (c) show different residence times of matter or elements in the CZ (infinite, median and small, respectively). The angle between the spiral's tangent and the radius of the nested circles indicates the velocity. A flat spiral indicates a slow movement and thus a long residence time in the reservoir. (d) and (e) indicate the direction of the matter or element flux. A centrifugal arrow means that the element flux is directed from the atmosphere to the deepest CZ layers. A centripetal arrow means that the flux of element is directed from the deep CZ to the atmosphere. (f) corresponds to element or matter fluxes leaving the CZO and not cycled within the CZO. (g) could represent biogeochemical cycles closing at the level of the CZO.

Ideally, we should be able to give a quantitative dimension to the angle of the spirals to register the speed at which elements diffuse and migrate through the various envelopes. It is the duration of the process that would characterize a spiral as having a sharper or a wider angle. The length of

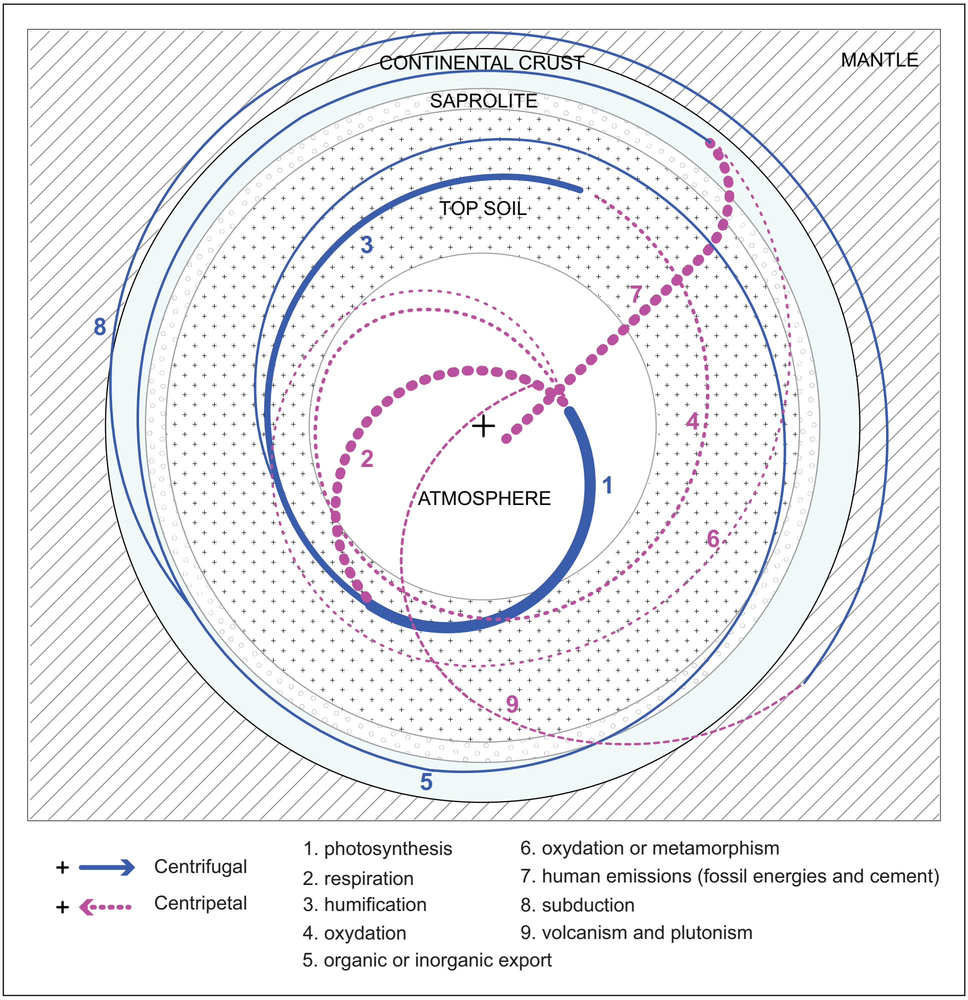

Figure 6. Scheme showing the capability of the Gaia-graphic view developed in this paper to represent the carbon cycle, taken as an example of cycle. The different processes (events) from 1 to 9 are described in the text. Color and thickness of the different lines describe the direction (centripetal or centrifugal) and flux (mass per unit of time) of the different events involved. Residence time in a given circle is figured by the steepness of the spiral. The short-term carbon cycle created by photosynthesis and respiration processes is characterized by bigger fluxes that the subduction of carbon in the mantle. Note that the importance of the anthropogenic flux associated to fossil fuels: from deep layers to the atmosphere, rapid injection and big flux compared with the geological flux of carbon burial.

the spiral is an indication of the residence time of each element in each reservoir. It is thus possible to propose a sort of *visual grammar*, a repertoire of conventions and symbols that could allow us to map the various signatures of events we wish to foreground (Figure 5). No matter how useful the localization of events in space has been, CZ scientists would agree that *how* you position an event in geochemical cycles has more relevance to understanding the Earth's dynamics.

As an application of this new system of coordinates, we illustrate how the carbon cycles might be represented in Figure 6.

The example of the carbon biogeochemical cycle is particularly illuminating. A carbon atom in the form of CO_2 enters into photosynthesis (1), a reaction triggered by the sun energy, and passes into the biomass and soil reservoirs where it is either respired quickly and released to the atmosphere (2) or transformed into refractory molecules (humification) (3). In the first case, the carbon cycle is described by a circle or spiral with a very short residence time (lines perpendicular to the circles) while in the second, the residence time of C in the soil circle can be much higher (3). The thickness of the spiral is scaled on the intensity of the flux. Soil organic carbon is susceptible to be being respired (4) or being exported from the ecosystem to the sea by rivers (organic or inorganic C) and can eventually leave the CZ and be embraced in a much wider spiral leading to the geological formation of hydrocarbons and limestones (5). In our new representation, the rapid processes of photosynthesis and soil respiration are described by centrifugal and centripetal lines respectively, with almost no angle, meaning that the residence time of the carbon atom is very short. To represent that carbon is incorporated into even deeper soil horizons and at a slower rate, we assign an angle to the line describing its cycle, thereby portraying carbon's much longer stay in the top soil reservoirs (3) before being respired and coming back to the atmosphere (4). For carbon exported from the soil and incorporated into rocks such as limestone and fossil organic carbon (5), the spiral would be even flat. Carbon subducted into the mantle would describe a quasi circle indicating a quasi infinite residence time (8). The restitution of rock carbon to the atmosphere is done either slowly when natural processes such as fossil carbon oxidation or metamorphism (6) or volcanism and plutonism (9) operate (8), or rapidly when carbon is burned by humans (7). In this case, the human shortcut is represented by a large vertical line rapidly (thus perpendicularly to the circles) bringing back carbon from the external envelopes (the deeper envelopes) to the center.

To make sense of such a representation, it is essential not to confuse it with the usual images attempting to represent the globe *in toto*. The anamorphosis we propose represents only the relevant cycles *as they occur at a specific site* – ideally a CZ observatory. So, every time you change the initial position, the distribution of cycles visible in such a place will provide a different picture, each site having its own unique signature. This is an essential goal of our alternative representation: to be able to picture the *heterogeneity* of the Earth. It is also important to recognize that in every site, the cycles we wish to represent are not limited to the CZ strictly speaking but may extend much further in time and space.

Conclusion

The main reason we insist on the importance of an alternative localization system is that it is crucial to situate the human role at the time of the Anthropocene. In the older cosmology, the problem with the human role was that its diminutive size made it invisible compared with the vast expanse of the infinite universe or the gigantic size of geophysical phenomena. The main problem of accepting the novelty of the Anthropocene is precisely to reconcile such a diminutive scale with the extent of the chemical and geological transformations of the 'human' taken as a whole. In the projection we are working on, the human influence is now fully visible, because its signature in the set of spiraling cycles is clearly detectable.

True the human shape does not appear as a clear-cut layer on top of other geological and biological phenomena, but it is all for the better. It now appears for what it is geochemically at the time of the Anthropocene: an exchanger, a switch, a shape changer, an interchange of cycles. In some of those cycles human industry is an accelerator – such as with CO_2 circulation; in others it takes over almost entirely – as in the nitrogen cycle where an industry that did not exist 150 years ago now dominates (Bouwman et al., 2009). While a unified vision of the human is lost, another vision appears that gives full weight to the exchange, transformation and dispersion of geochemical cycles with which it is associated.

It is traditional in history of science to describe the scientific revolution, to use Koyré's famous title, as a move from 'the closed cosmos to the infinite universe' (Koyré, 1957). However, we do not reside in such an infinite universe. On the contrary, it becomes more and more obvious, as we familiarize ourselves with the idea of an Anthropocene world view, that Koyré's title should be exactly reversed: we moved from an infinite universe that we were used to describing cartographically and astronomically to a closed cosmos that we have great difficulty representing (Hache, 2014). This countermove creates a disconnect with the usual ways of giving a place and a role to humans. As Peter Sloterdijk would argue, we are not creatures of the 'outside', but rather we live inside envelopes of which we are slowly becoming conscious through a process of 'explicitation' (Sloterdijk, 2009). While in the planetary view to localize is to situate a point through longitude and latitude by applying a grid coming from outside (Debaise, 2017), the Gaia-graphic view creates a sideways representation of cycles the movement of which draws the membranes inside which we all reside.

By modifying the traditional projection that left the human on the surface of a sphere in the middle of an infinite universe, we have attempted to open a space that was never clearly deployed. There is still an infinite space, but it is no longer that of an isotropic universe; it is that of the infinitely complex, folded, bounded and interwoven geochemical cycles initially born in the CZ, the only territorial attachment that we might be ready, at the time of the Anthropocene, to study and to care for.

Once a cosmographic practice is in place, a future second step is possible – applying that practice to the representation of data produced by the different CZOs.

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